INDIAN INSTITUTE OF TECHNOLOGY
KHARAGPUR

NPTEL
ONLINE CERTIFICATION COURSE

On Industrial Automation and Control

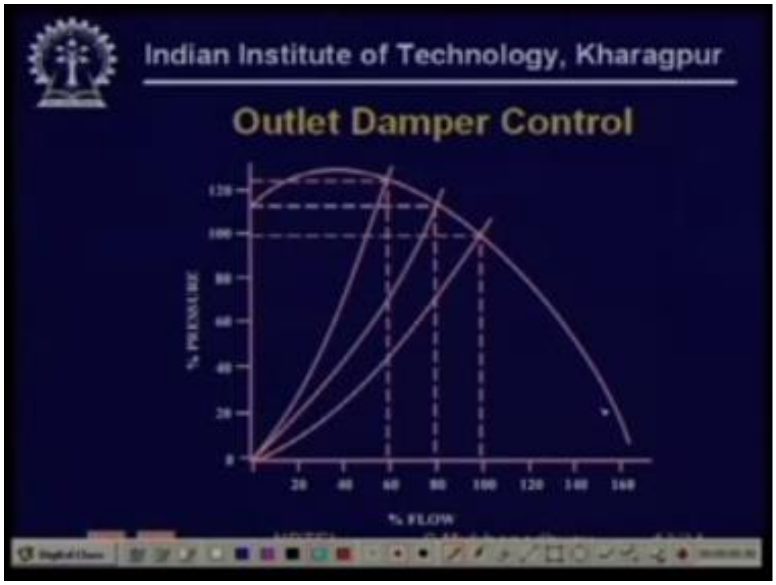
By Prof. S. Mukhopadhyay
Department of Electrical Engineering
IIT Kharagpur

Topic Lecture – 45
Energy Savings with Variable Speed Drives (Contd.)

(Refer Slide Time: 00:21)

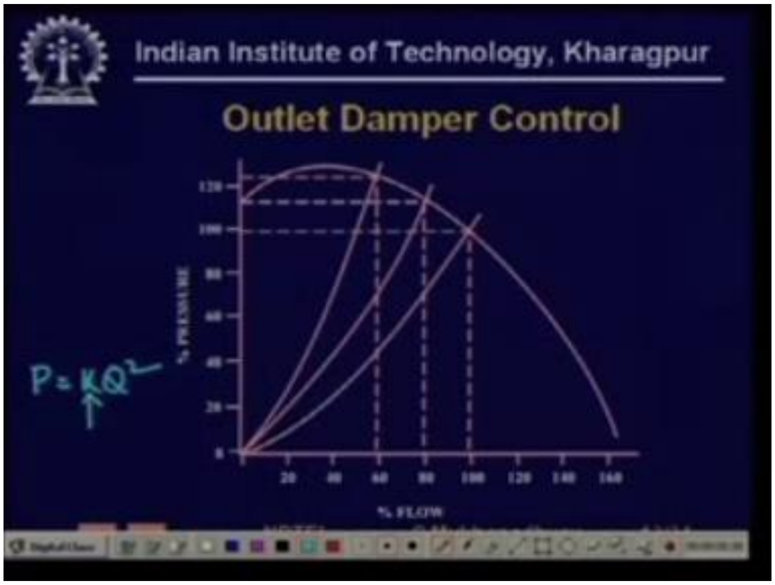
But as we shall see that they can save considerable amount of energies.

(Refer Slide Time: 00:26)



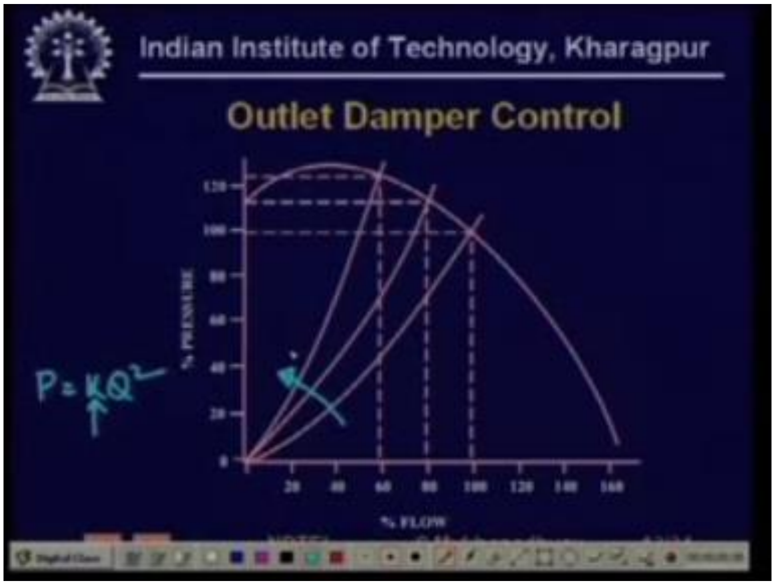
So let us see so now let us look at what happens to the operating characteristics when you have damper control so here is the fan curve you can see that now a damper is essentially actually puts a resistance so basically we had this so it you can consider the damper to be part of the load so as you are closing the damper this load characteristic.

(Refer Slide Time: 00:56)



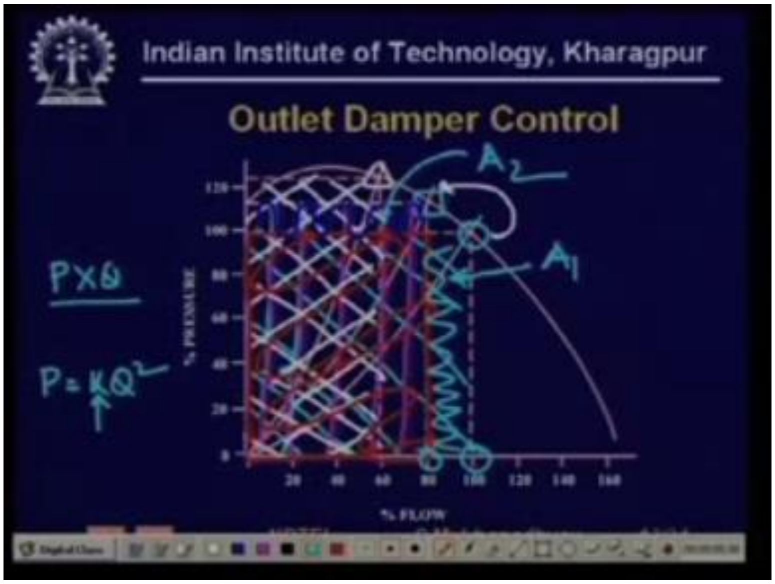
Of $P = KQ^2$ this K value is gradually increasing which means that as the damper is closing more and more pressure is required to drive a given flow that is natural.

(Refer Slide Time: 01:11)



So as the damper is closing this curve is shifting this way because this is increasing k now what is happening to the energy the energy in a fan the energy being delivered is P x Q.

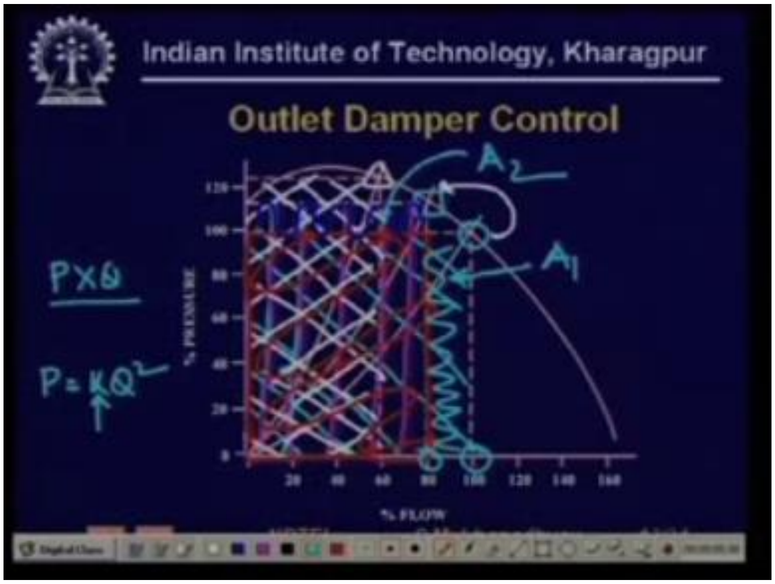
(Refer Slide Time: 01:30)



So in other words it is the area of this rectangle at any operating point at this operating point it is the area of this rectangle this is the area when you area at this operating point operating point number two then this is the actually I could have taken a different color okay let me take this color so at the other operating point this is the and when you take a third operating point which is this then this is the area energy demand okay so you can very well see that what is the difference how if you move from this operating point to this operating point.

What is the what is the difference in energy the difference in energy is actually this part is common this part is common between them and you see that so this is common so this is gone on the other hand this is gone and this is added so the energy saving is actually comes down to the difference between this areaA1 and this areaA2 which is very low so you see that even if you have moved from this operating point you have come from one hundred percent to eighty percent flow the energy has not fallen by that much amount.

(Refer Slide Time: 03:39)



The energy has fallen only by the amount of difference between these two areas right in fact the same so the energy fall is not so much.

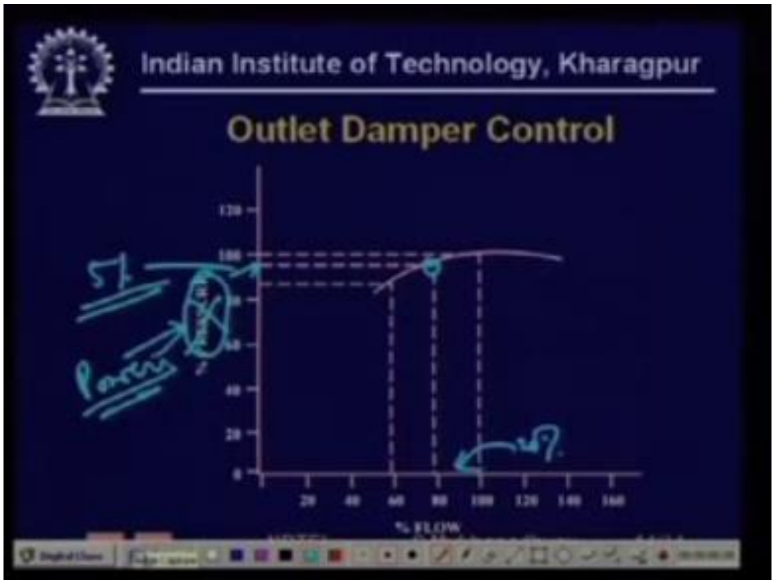
(Refer Slide Time: 03:51)

So in fact you can see the energy curve.

(Refer Slide Time: 03:54)

So you see that in damper control as you are going from 100 to 80 the energy fault is only this much very low so you have so there is a 20-percent flow reduction but there is probably a five percent energy reduction power reduction this is not pressure this is power is wrong okay so that is why this method is not so energy efficient you are not saving energy flow is reducing but you are not flowing energy but it is a very simple method you do not require much unique where either a valve or a damper you close and open it.

(Refer Slide Time: 04:49)



Now what happens.

(Refer Slide Time: 04:50)

If you do a variable speed drive.

(Refer Slide Time: 04:52)

(Refer Slide Time: 04:54)

CFM	DUTY CYCLE	HORSE-POWER	WEIGHTED HP
100	10	35	3.5
80	40	35	14.0
60	40	31	12.4
40	10	27	2.7
		Total	32.6

Now this is that particular case so if you want to see this we can come too we can let us come to the if you want to see this figure so what does it say that for our example and for the fan curve that we have seen if you take a hundred percent CFM hundred percent flow the horse power requirement becomes 35 we will see how it comes to 35 from those curves if you have eighty percent the horse power requirement is also 35hardly any reduction if you have sixty percent.

(Refer Slide Time: 05:37)

CFM	DUTY CYCLE	HORSE-POWER	WEIGHTED HP
100	10	35	3.5
80	40	35	14.0
60	40	31	12.4
40	10	27	2.7
		Total	32.6

It falls to 31 if you have forty percent it falls 27 and from the load characteristics we have seen that hundred percent low stage.

(Refer Slide Time: 05:46)

Ten percent time so per hour what percent is 3.5 is the weighted horse power.

(Refer Slide Time: 05:56)

(Refer Slide Time: 06:00)

CFM	DUTY CYCLE	HORSE-POWER	WEIGHTED HP
100	10	35	3.5
80	40	35	14.0
60	40	31	12.4
40	10	27	2.7
		Total	32.6

So 35 horse power level stays 10.10% of the time so therefore weighted horsepower is 3.5 we are try to calculate the average horsepower right.

(Refer Slide Time: 06:16)

CFM	DUTY CYCLE	HORSE-POWER	WEIGHTED HP
100	10	35	3.5
80	40	35	14.0
60	40	31	12.4
40	10	27	2.7
		Total	32.6

Similarly 35-percent again 35 stays 40% of the time that is 14 then 31 stairs forty percent of the time thus 12.4 and 27 stays ten percent of the time that is 2.7 so the average horsepower requirement is 32.6 remember this figure we will come back and see that if you do a variable speed drive what it what for the same pump and for the same load profile if we had a variable speed drive what would have been this figure.

(Refer Slide Time: 06:47)

CFM	DUTY CYCLE	HORSE-POWER	WEIGHTED HP
100	10	35	3.5
80	40	35	14.0
60	40	31	12.4
40	10	27	2.7
		Total	32.6

So we have a 32.6 horsepower average horse power requirement for the load and the pump right.

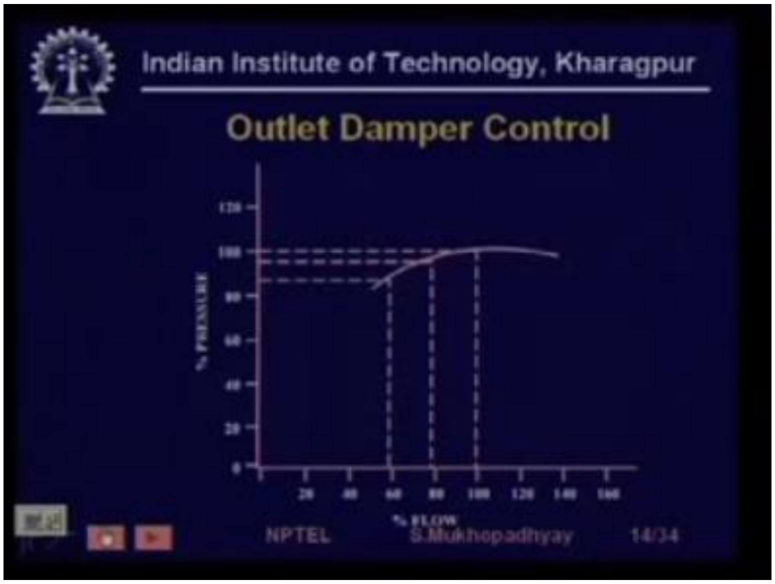
(Refer Slide Time: 06:53)

So just we would also like to see how these 35 35and 31 figures are located because otherwise you may not believe me so let us go back and oops okay.

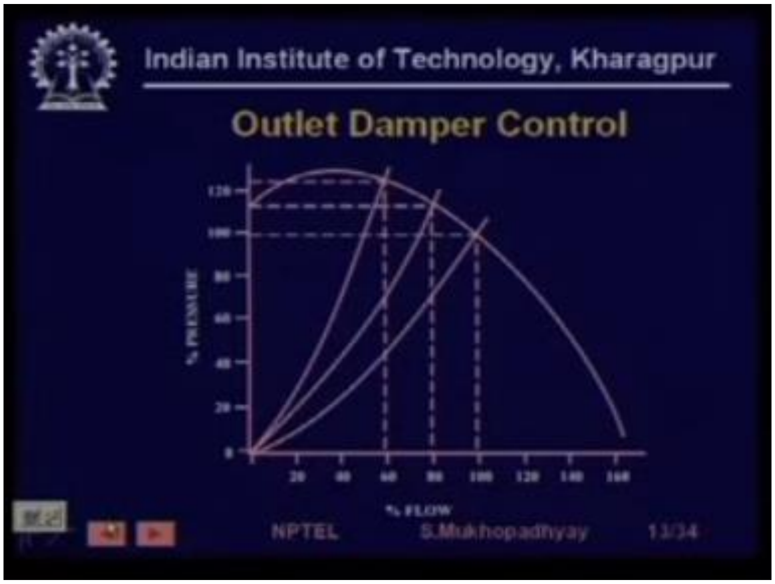
(Refer Slide Time: 07:11)

How do we close this ok can I go back to the.

(Refer Slide Time: 07:22)



(Refer Slide Time: 07:23)



(Refer Slide Time: 07:25)

(Refer Slide Time: 07:26)

(Refer Slide Time: 07:27)

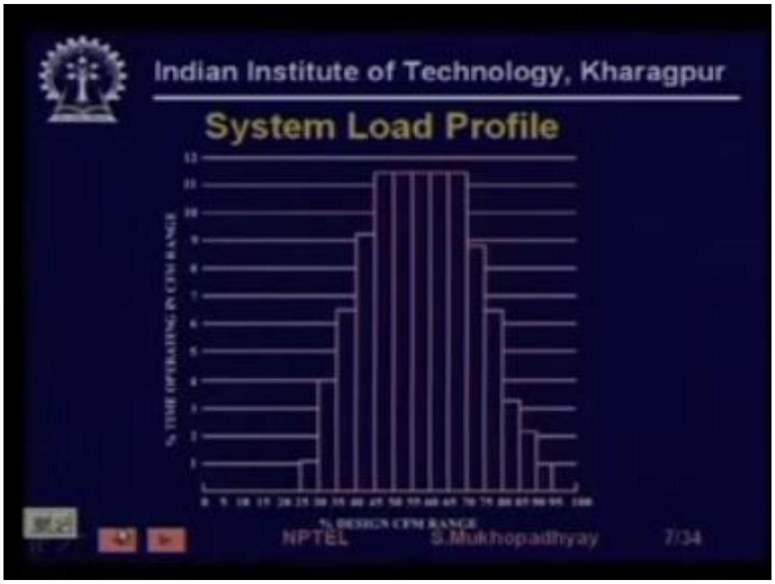
So i will i am going back.

(Refer Slide Time: 07:29)

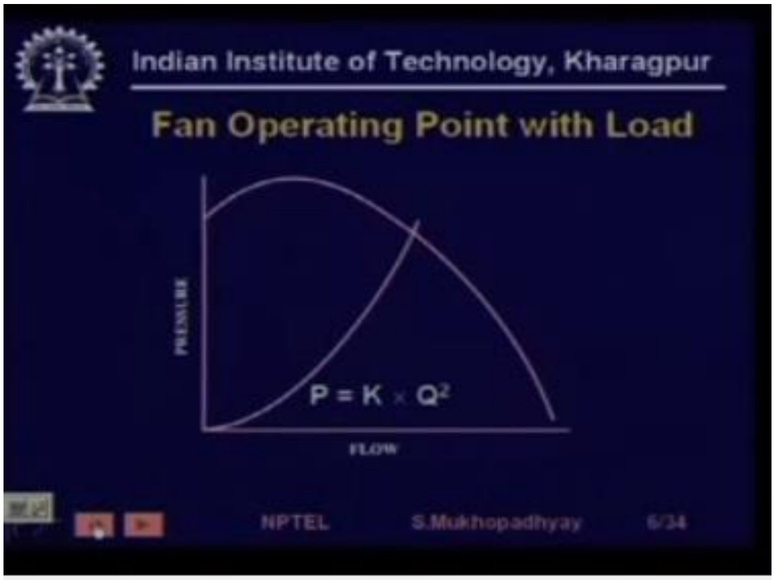
To the --

(Refer Slide Time: 07:30)

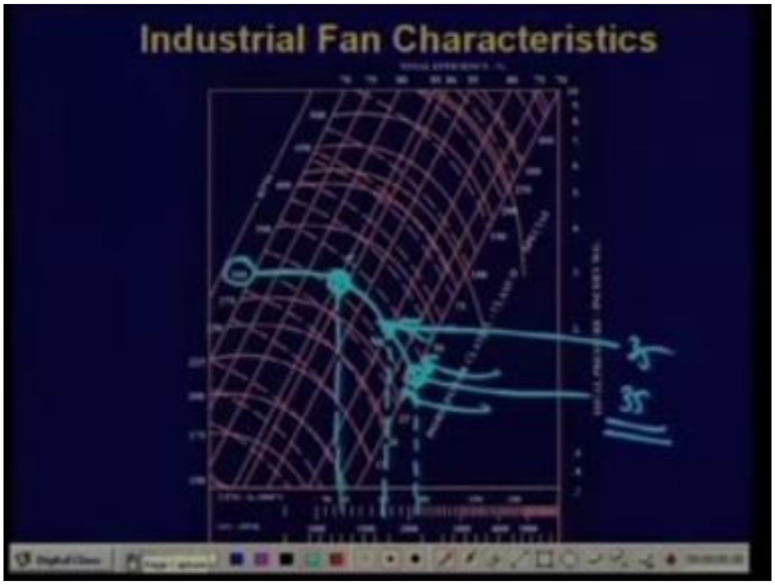
(Refer Slide Time: 07:31)



(Refer Slide Time: 07:33)



(Refer Slide Time: 07:34)

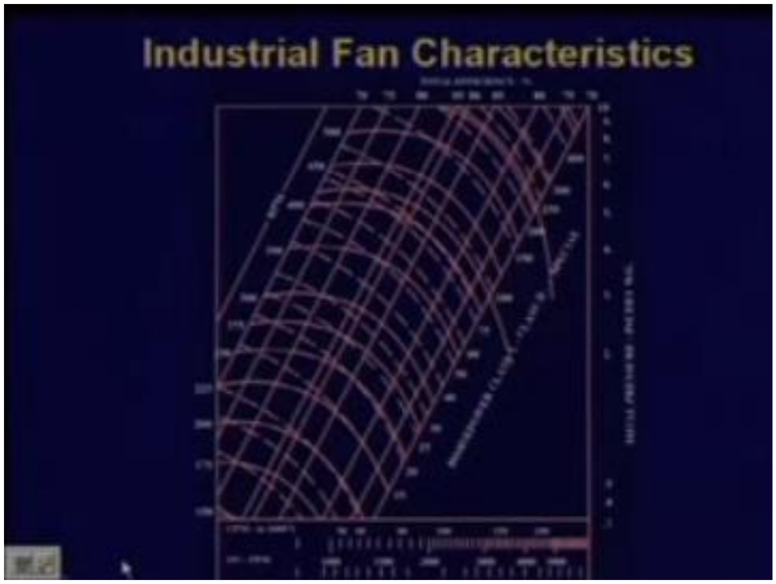


Fan car just to show you all right yeah so we are the fan character so let us see that it actually this has been calculated with a fan RPM of about 300 so this is the 300curve so we are looking at this curve this is the constant rpm 300 curve okay and we are at hundred percent okay so this is somewhere over here so you see that it is somewhere over here can you see that so it is somewhere over here okay now you see what is the power requirement here look at these curves this is 30 this is this is the constant 30 curve.

This is the constant 40 car 40 horsepower so where are we are at 35 now what happens when you are 80% flow that is when you are here so when you are here you are roughly here so you are at 80% curve now you see that where are you this curve are moving pie in parallel so if it is 35 here it is going to be 35 here also that is why this is also 35 this is also 35 if you do 60% that is here where are you are 60% would be somewhere over here yeah so you are here so that is a little reduced you see this is the 30 curve.

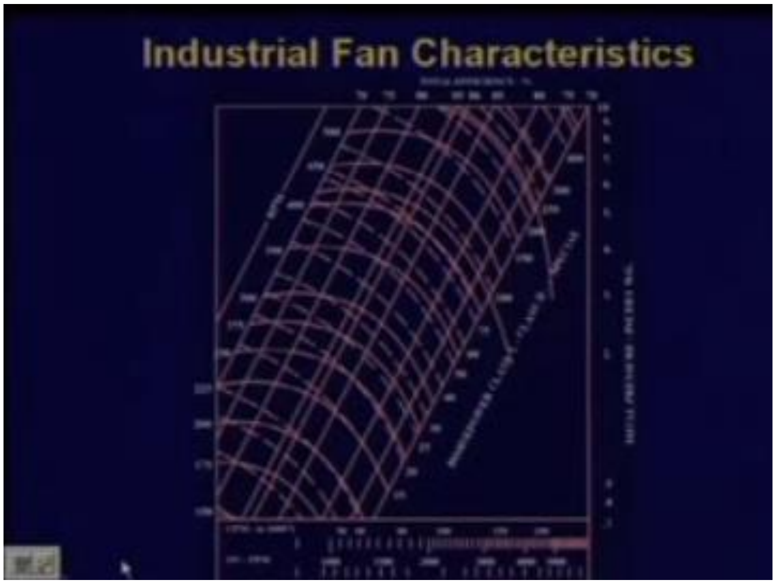
This is the 40 curve this is the 40curve so therefore and this is actually a nonlinear variation because 50 to 60 to 60 to 75 is gradually getting closer so there is something like 31, 31 did slightly reduced actually so this is how you get those figures.

(Refer Slide Time: 09:53)



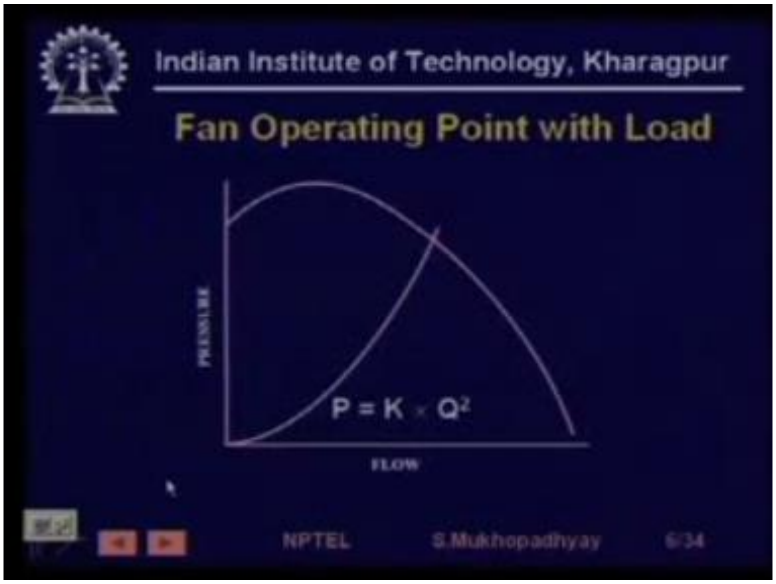
From an actual pumped characteristics okay.

(Refer Slide Time: 09:56)



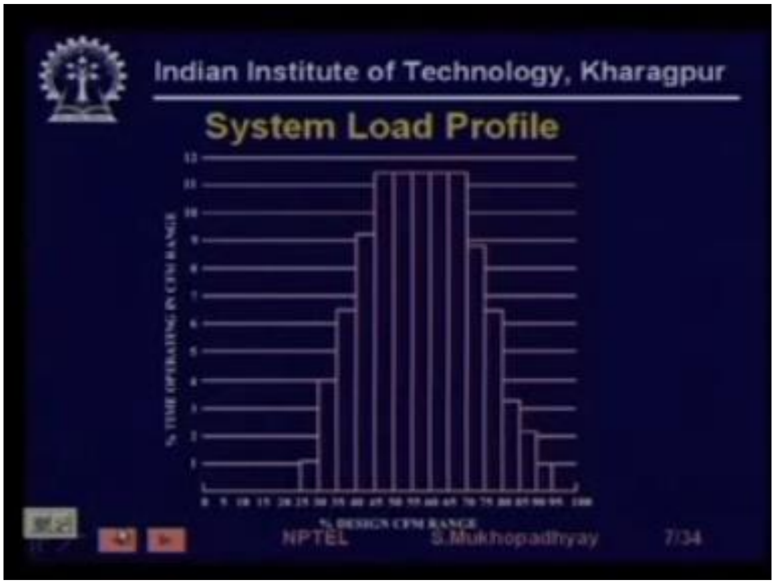
So now we go forward quickly again.

(Refer Slide Time: 09:58)



And.

(Refer Slide Time: 10:01)



(Refer Slide Time: 10:02)

(Refer Slide Time: 10:03)

(Refer Slide Time: 10:07)

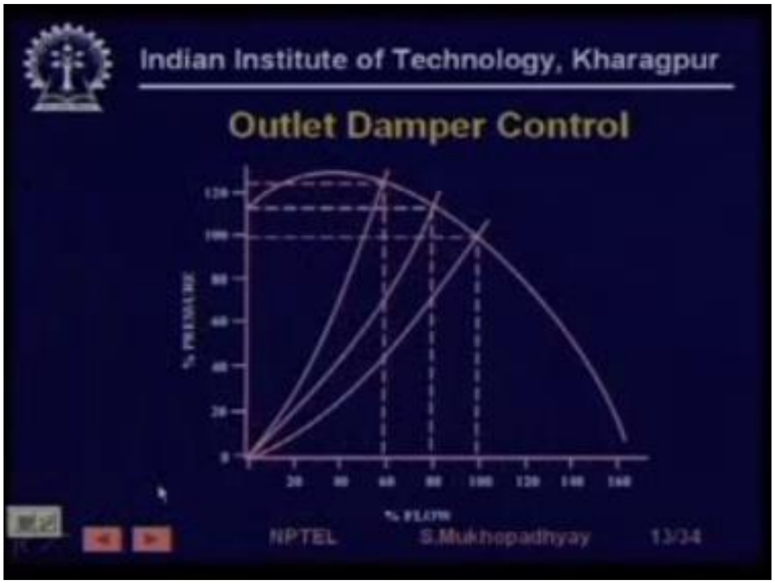
Go on to the variable.

(Refer Slide Time: 10:09)

Go on to the variable speed drive case and see what happens.

(Refer Slide Time: 10:12)

(Refer Slide Time: 10:15)



Right.

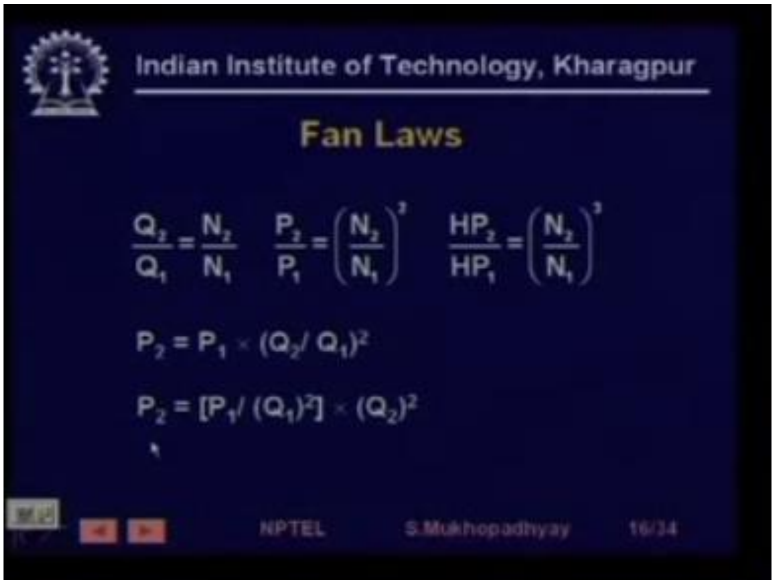
(Refer Slide Time: 10:16)

So that is the case.

(Refer Slide Time: 10:20)

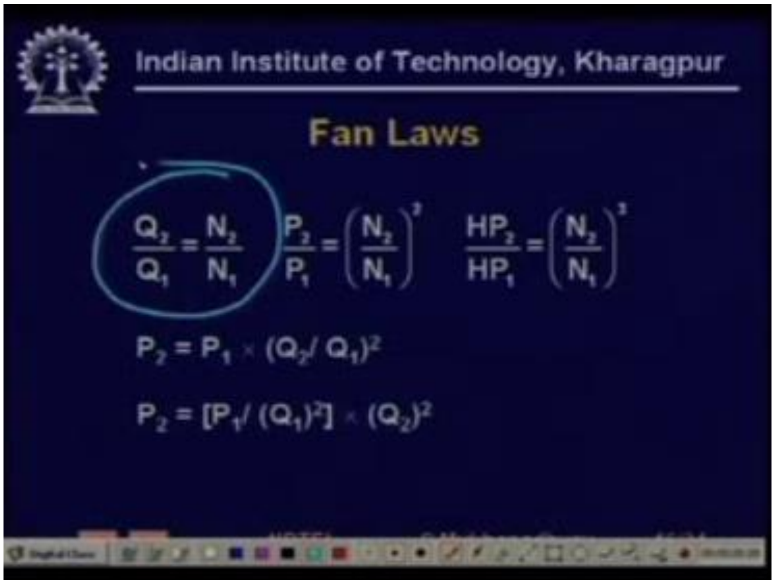
CFM	DUTY CYCLE	HORSE-POWER	WEIGHTED HP
100	10	35	3.5
80	40	35	14.0
60	40	31	12.4
40	10	27	2.7
		Total	32.6

(Refer Slide Time: 10:25)



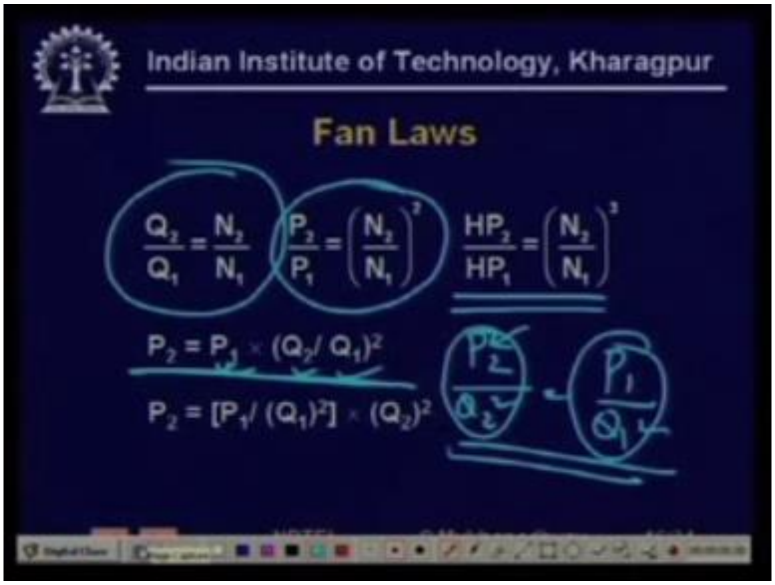
Now here before we discuss that we need to understand what are known as the fan laws so what are the fan laws the fan laws say.

(Refer Slide Time: 10:33)



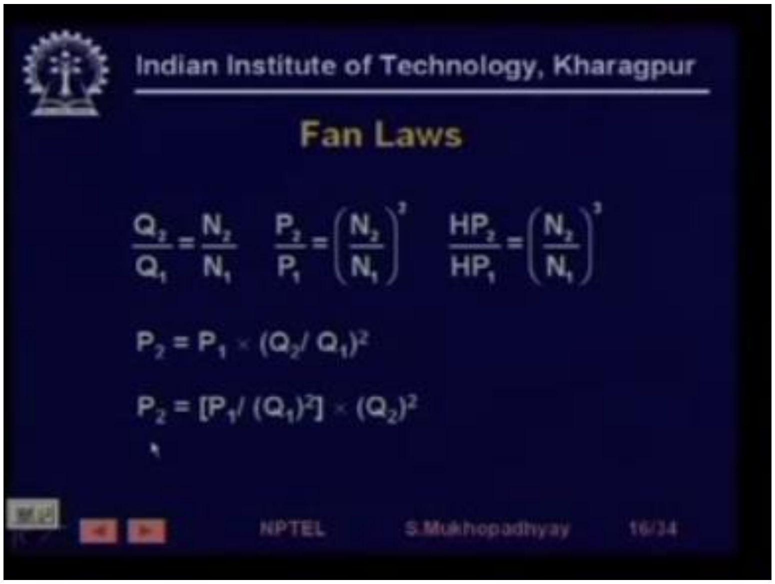
That in a fan roughly Q2 by Q1= N2 by N1 if you operate if you change the speed the curve shifts in such a manner that on the Q axis you are going to get proportional these things and P2 by P1 = N2 by $N1^2$ square so the horsepower variations.

(Refer Slide Time: 10:58)



Are going to be in two by going to vary as N2 by $n1^3$ so similarly so if you know this Q2 by Q1 and you know P1 you can calculate P 2 by this formula because P2 byP1 = Q 2 xke 1 whole square if you if you eliminate N from these two then you get basically P2 by Q^2 = P1 by $Q1^2$ so P2 by $Q2^2$ = P1 by $Q1^2$ these are this is at speed N 2 and these two are at speed N2 and these two are at speed N 1 okay so now having known that.

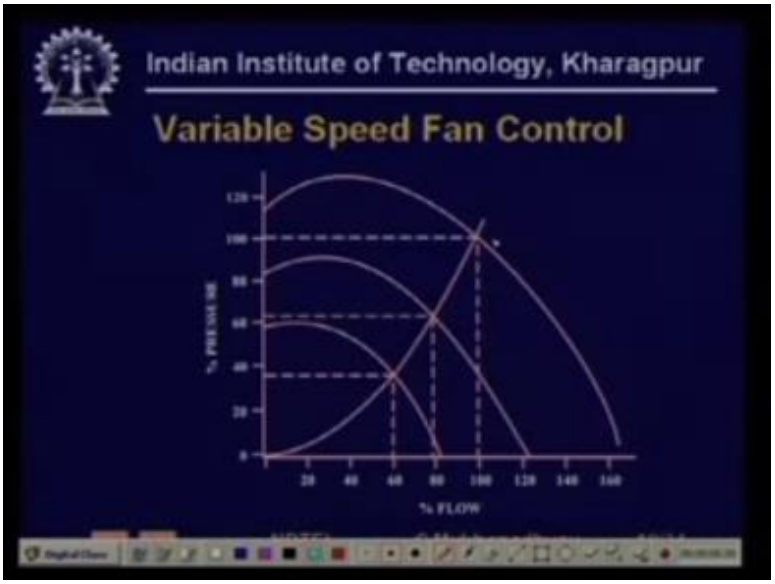
(Refer Slide Time: 11:42)



We come back.

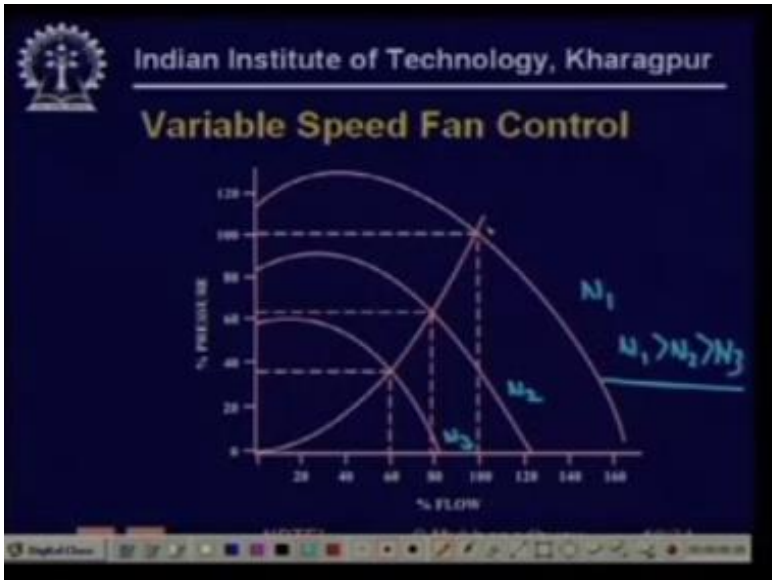
(Refer Slide Time: 11:44)

(Refer Slide Time: 11:58)



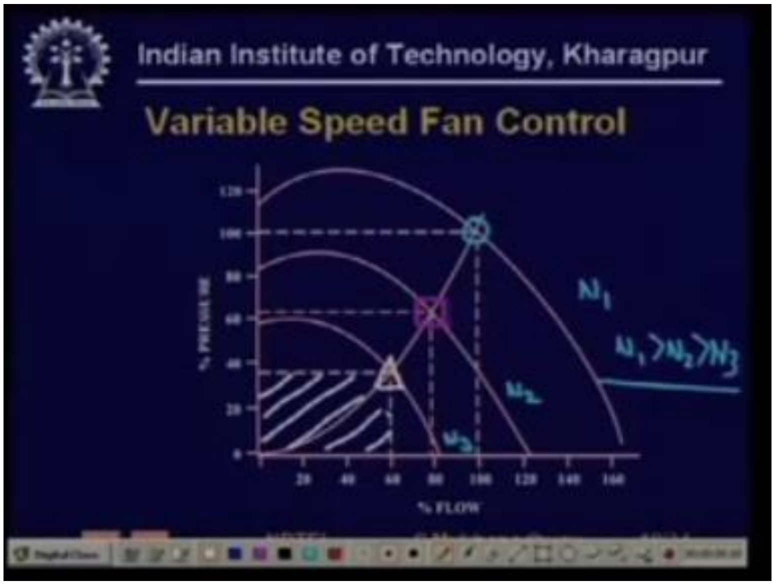
Right so we see this variable speed fan control so now what happens is that if you want to reduce the speed we are not going to put any damper or any valve in other words the characteristic of the system remains unchanged now we are changing the speed of the fan so the fan characteristic shifts.

(Refer Slide Time: 12:14)



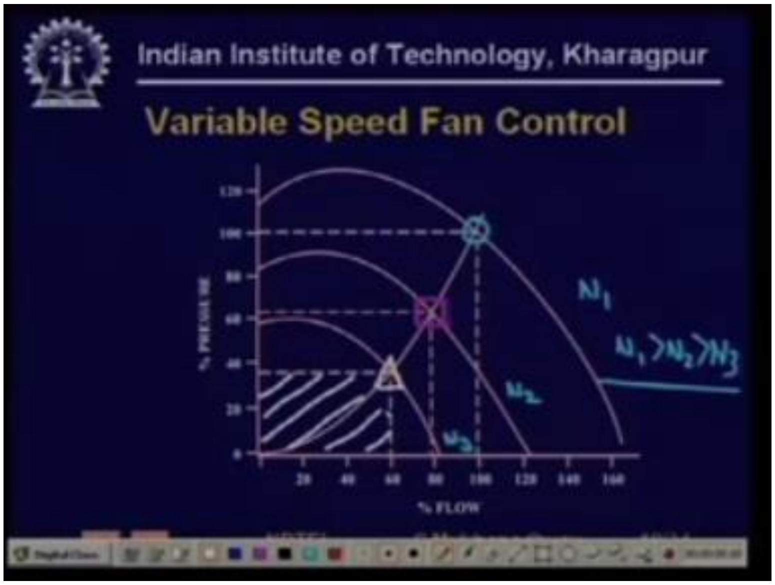
So this is let us say N1 this is N2 and this is N3 and N1 is greater than N2 is greater than N3 okay so now what happens is that now the operating point will change along.

(Refer Slide Time: 12:33)



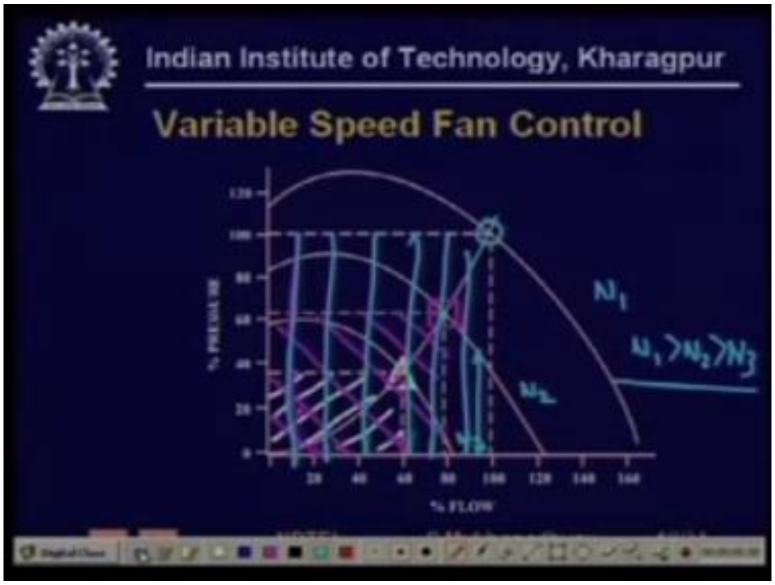
This is the first one then this is the second one and this is the third one so what happens to the power requirements now so the power requirement for the last one is this see previously as we were reducing flow pressure was going up so the power was not falling now as we are reducing the speed.

(Refer Slide Time: 13:02)



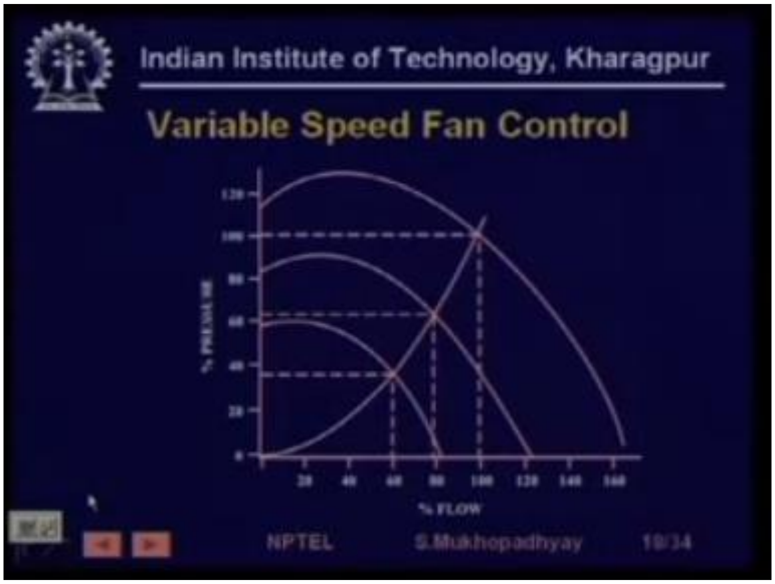
It is not just that the flow is it you seen it is the pressure is also falling right and very rapidly too so what happens.

(Refer Slide Time: 13:11)



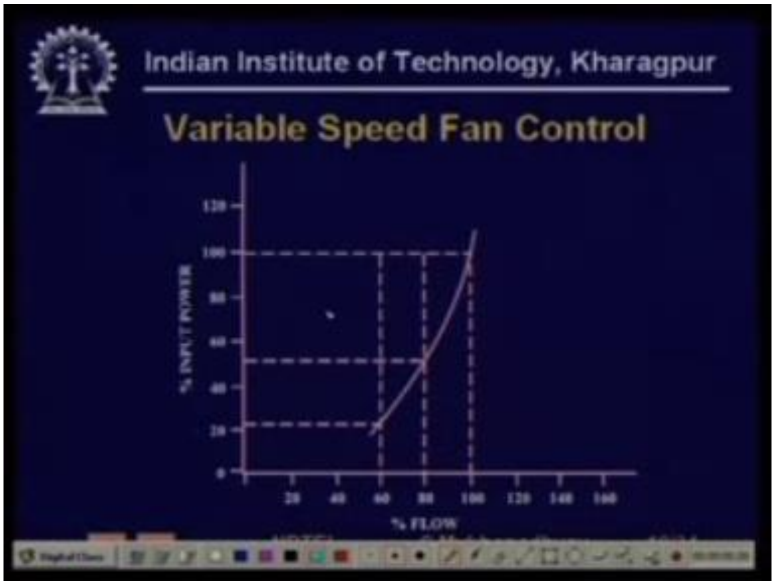
So this is the area required this is the energy and similarly for this case second operating point this is the energy and for the third operating point this is the energy so for the third operating point this is the energy so you can very well understand that energy falls very sharply so that is why.

(Refer Slide Time: 13:43)



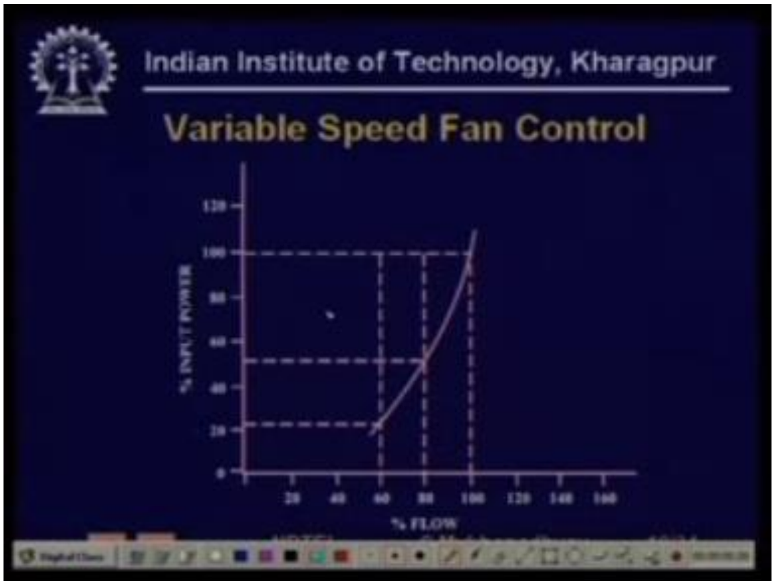
You are going to get a huge benefit in terms of energy.

(Refer Slide Time: 13:48)



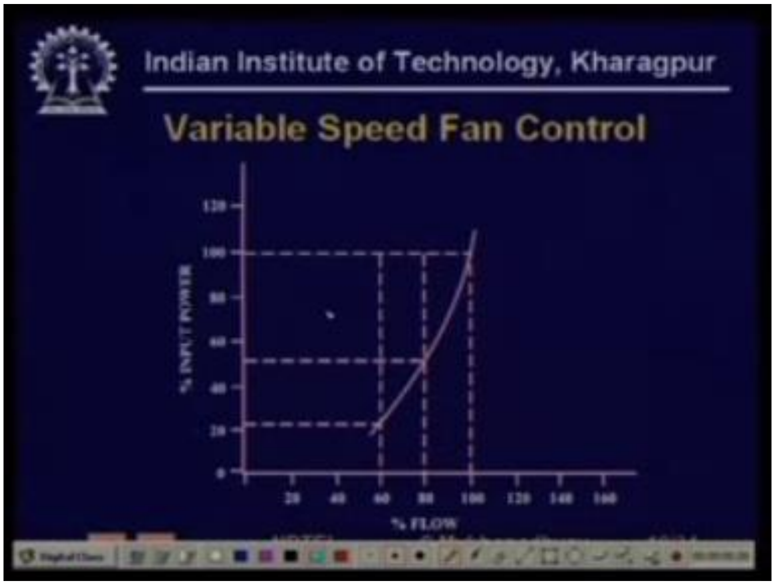
Savings right so you can now see that the power curve how sharply it falls compared to what you had seen in the case of the outlet damper control.

(Refer Slide Time: 14:03)



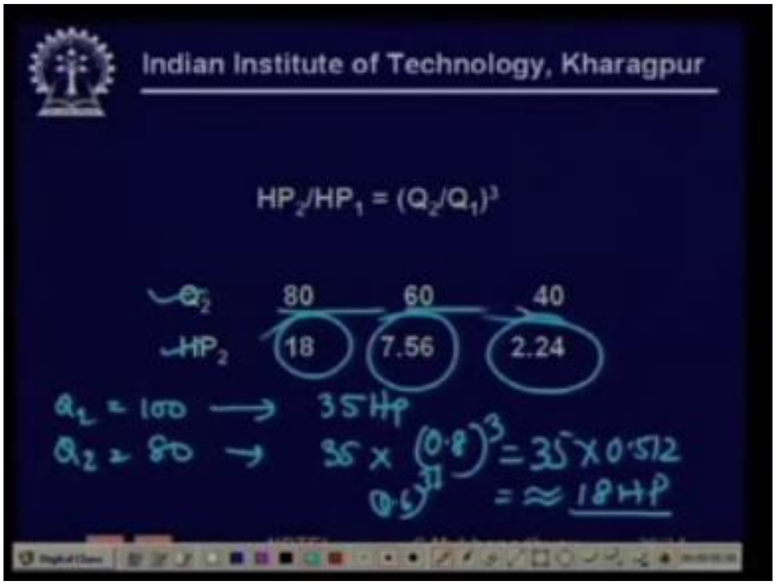
So this is the essence of energy so this shows that how energy saving variable speed drive can be.

(Refer Slide Time: 14:12)



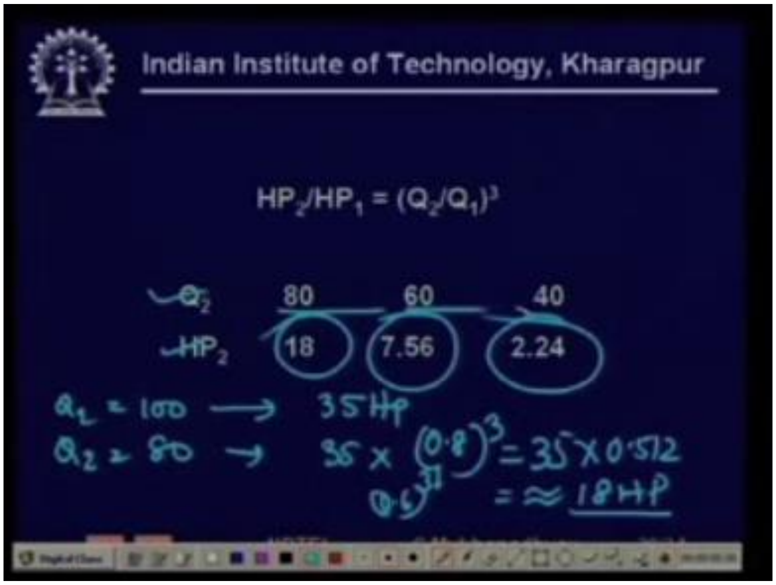
And just to you know drive the point home.

(Refer Slide Time: 14:16)



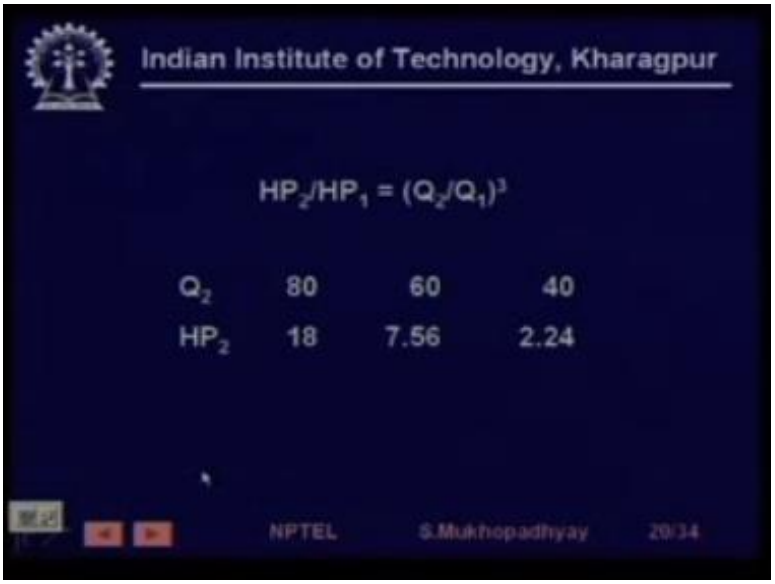
We are going to show you that you know we are we are just we are just applying that same formula that that what happens is that remember that at Q1 equal to hundred we had a HP requirement of 35 h so with Q1 equal to 80 Q2 equal to80 HP requirement will be 35 into 0.8whole cube which is equal to 35 into 0.512 which is almost equal to 18horsepower so this is 18 similarly if you multiply this by 0.6 whole cube then you will get 7.56 similarly 2.2 so these are the horsepower requirements now applying the fan laws and you can get very similar figures if you see the fan clubs because the fan curves.

(Refer Slide Time: 15:24)



Right.

(Refer Slide Time: 15:28)



So here we are.

(Refer Slide Time: 15:30)

CFM	DUTY CYCLE	HORSE-POWER	WEIGHTED HP
100	10	35	3.5
80	40	18	7.2
60	40	7.56	3.024
40	10	2.24	0.224
		Total	13.948

So now let us see the energy average horse power requirements when you are varying the speed the average person.

(Refer Slide Time: 15:38)

Case is the same 33.5 the eighty percent case is now totally different this was 35 remember this was 31 and this was 27 so now the average horse power requirement is 32where the previous one 13 the previous one was some 32 points something so you can imagine that what amount of power saving has been achieved almost 20horsepower which is fourteen hundred kilowatts.

(Refer Slide Time: 16:10)

CFM	DUTY CYCLE	HORSE-POWER	WEIGHTED HP
100	10	35	3.5
80	40	18	7.2
60	40	7.56	3.024
40	10	2.24	0.224
32.72		Total	13.948

(Refer Slide Time: 16:20)

CFM	DUTY CYCLE	HORSE-POWER	WEIGHTED HP
100	10	35	3.5
80	40	18	7.2
60	40	7.56	3.024
40	10	2.24	0.224
		Total	13.948

Right fourteen thousand.

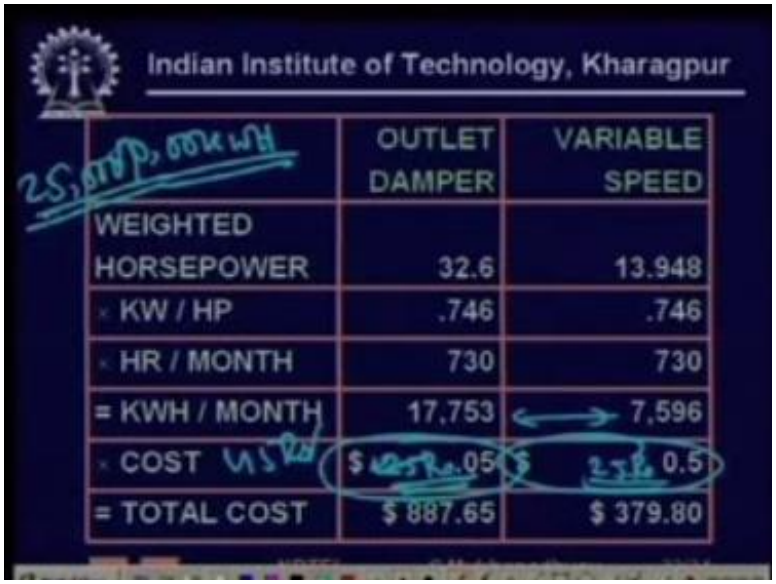
(Refer Slide Time: 16:27)


Indian Institute of Technology, Kharagpur

	OUTLET DAMPER	VARIABLE SPEED
WEIGHTED HORSEPOWER	32.6	13.948
× KW / HP	.746	.746
× HR / MONTH	730	730
= KWH / MONTH	17,753	7,596
× COST US Rs	$ 2.5Rs .05	$ · 2.5Rs 0.5
= TOTAL COST	$ 887.65	$ 379.80

So yeah so this is you know this is a little calculation this is this dollar figure is because of the source from which this is taken but this turns out to be almost equivalent to ours if you take about 45 rupees per dollar so this becomes about 2.5 rupees which is a kind of an average rate not exactly it values from state to state it varies on various energy slabs and industrial energy rates are anyway not just depends on the kilowatt it also depends on the maximum demand so approximately speaking if you take 2.5rupees.

(Refer Slide Time: 17:09)



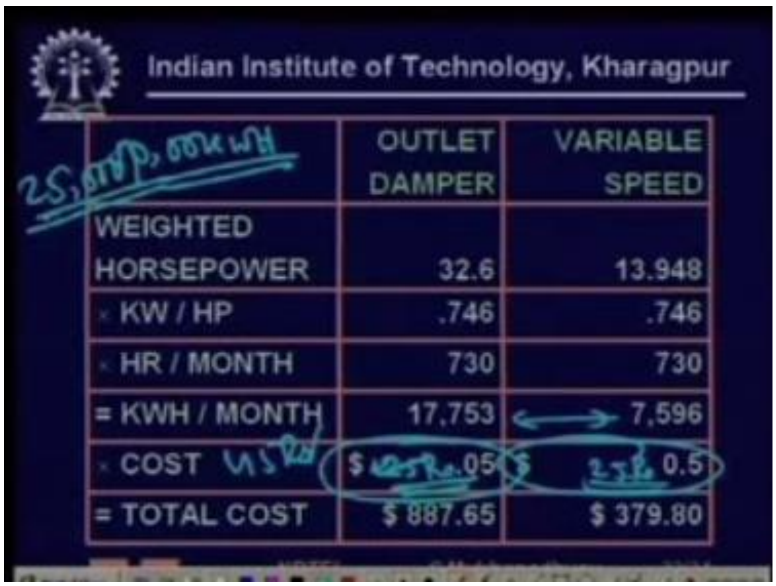
	OUTLET DAMPER	VARIABLE SPEED
WEIGHTED HORSEPOWER	32.6	13.948
× KW / HP	.746	.746
× HR / MONTH	730	730
= KWH / MONTH	17,753	7,596
× COST	$ [illegible].05	$ [illegible]0.5
= TOTAL COST	$ 887.65	$ 379.80

And if you take 2.5 two point five rupees here then you have you cannot inquire roughly you have a tent thousand kilowatt hour per month tent thousand kilo per kilowatt hour per month saving at 2.5 rupees per kilowatt hour that comes to be a 25,000rupees saving per month on a single fan now the question is whether this is justified so whether it is justified will depend on sea apart from the conservation ala spect of energy that we need to be energy-efficient we need to we need to because fossil fuel is not going to last forever etc if you ignore those things.

Then people are going to look at money so if you it all depends on its again remember that in the in the early lessons of the course we talked about capital cost and we cost and we talked about variable cost so energy is variable cost so whether people are going to resort to a simple damper type of control or whether the whether they will actually buy this variable speed drives depends on how much money is required to buy these drives and how much money is required to maintain them against how much savings these drives give so it is all this.

Basically because of this comparative these comparative figures which will decide practically speaking whether a particular industry is going to adopt this technology or the other now it so happens that you know why the outlet damper technology was more common is because the variable speed drive technology was not so developed it was not so robust so it was it was way too expensive so therefore people always often even if there was they were not energy-efficient people opted for this damper and valve control kind of techniques but now with the these variable speed drive drives really becoming robust and cost-effective it shows that it makes a lot of sense to acquire variable speed drives for such equipment okay.

(Refer Slide Time: 19:31)



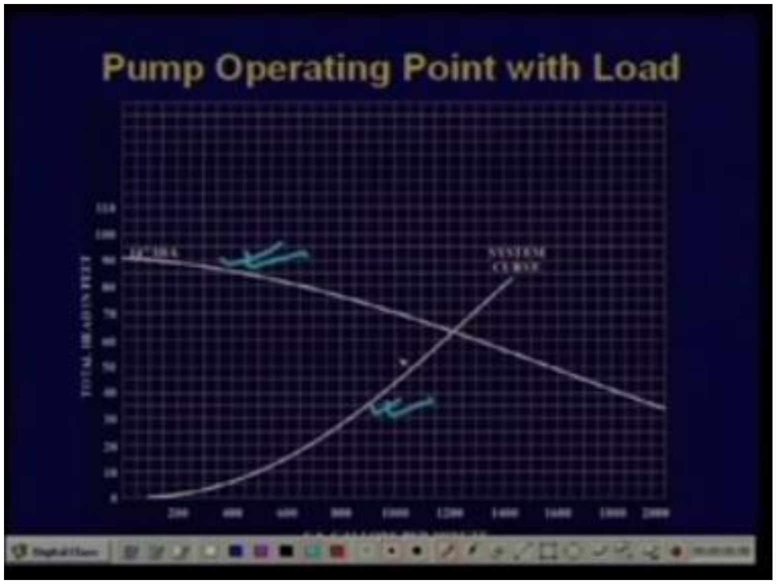
So this so basically it is the cost and the it is the capital cost of purchasing the equipment and the cost of the maintenance which decide whether these technologies are going to be adapted right so you see this shows that how important it is to make a technology cheap and to make a technology robust right otherwise it is not going to be adopted.

(Refer Slide Time: 20:02)

	OUTLET DAMPER	VARIABLE SPEED
WEIGHTED HORSEPOWER	32.6	13.948
× KW / HP	.746	.746
× HR / MONTH	730	730
= KWH / MONTH	17,753	7,596
× COST	$ .05	$ 0.5
= TOTAL COST	$ 887.65	$ 379.80

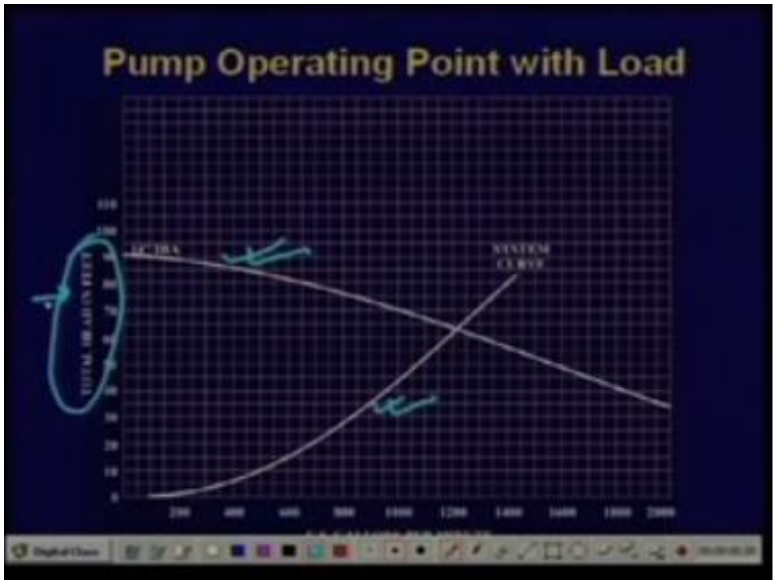
So we go move over to the case of pumps.

(Refer Slide Time: 20:07)



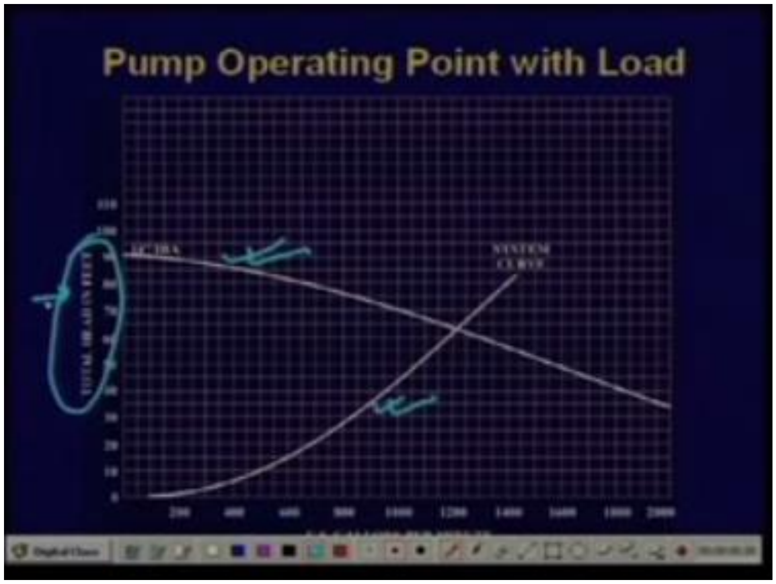
For pumps this is a pump characteristic again the same thing basically same thing so we are going to do this little bit fast so this is the pump characteristic and this is the system curve which is again you know of course there is a little difference in the sense that fans drive gases which are compressible and pumps drive liquids which are generally incompressible so there is a slight difference there but it looks essentially the principle is all the same.

(Refer Slide Time: 20:43)



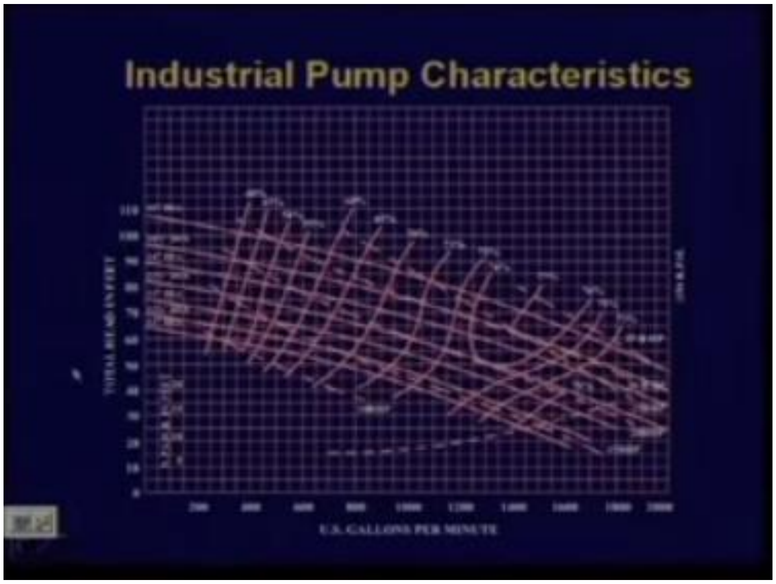
This side you have total head in feet of water right proper previously you had inches because that was gas this is liquid and you have.

(Refer Slide Time: 20:53)



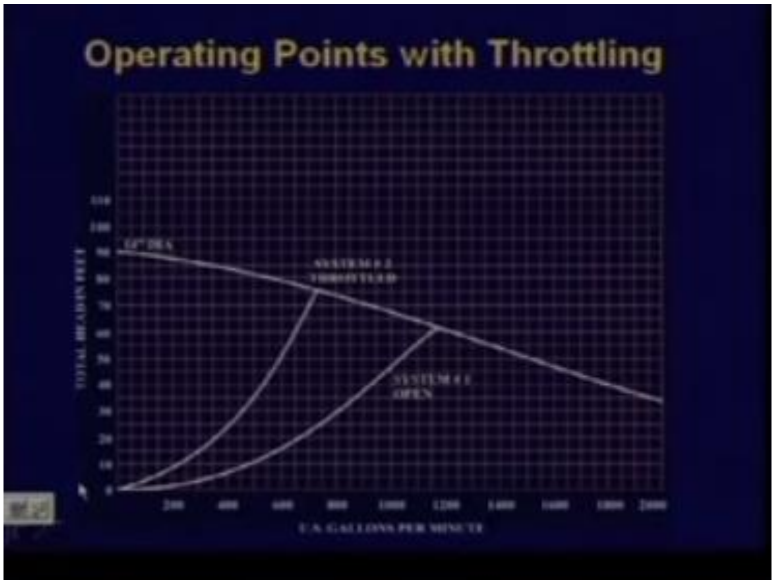
This is given in you can have you have to choose an unit because this is from and American reference so this is gallons per minute.

(Refer Slide Time: 21:11)

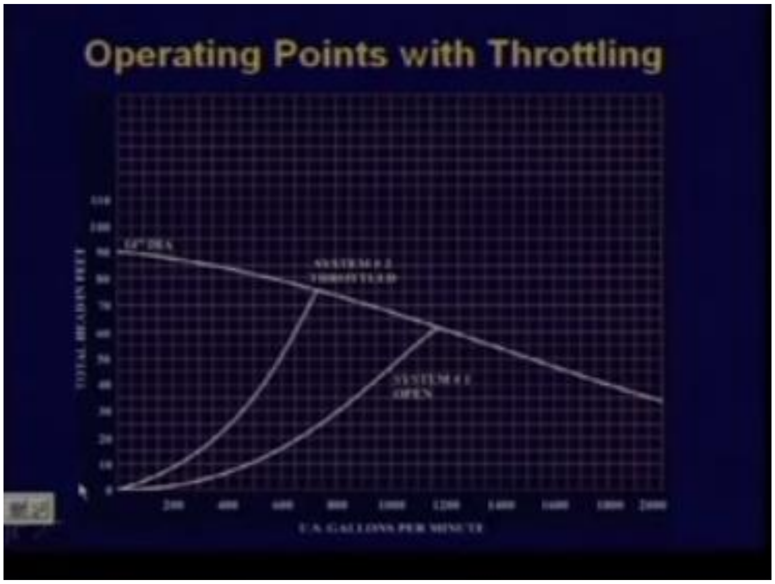


So similar to the fan characteristic you can have a pump characteristic where again you have the pressure up.

(Refer Slide Time: 21:21)

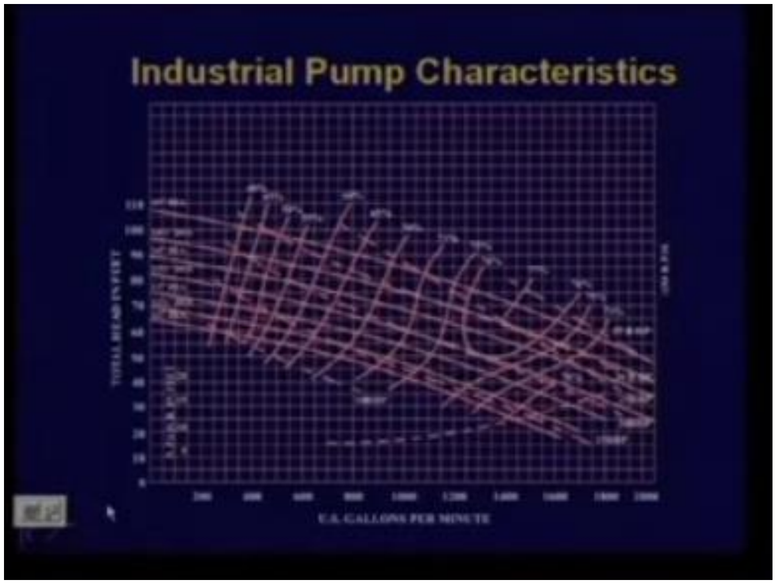


(Refer Slide Time: 21:29)



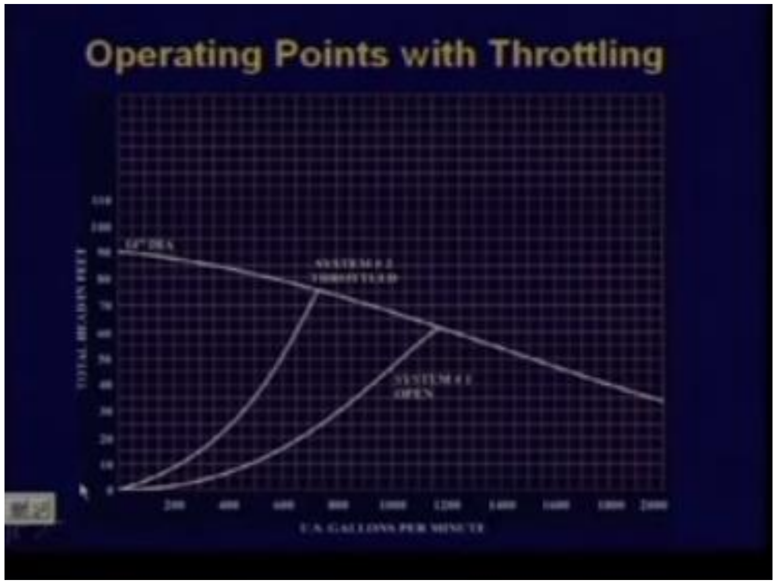
I made a mistake how do we go back now we do not have okay so.

(Refer Slide Time: 21:40)



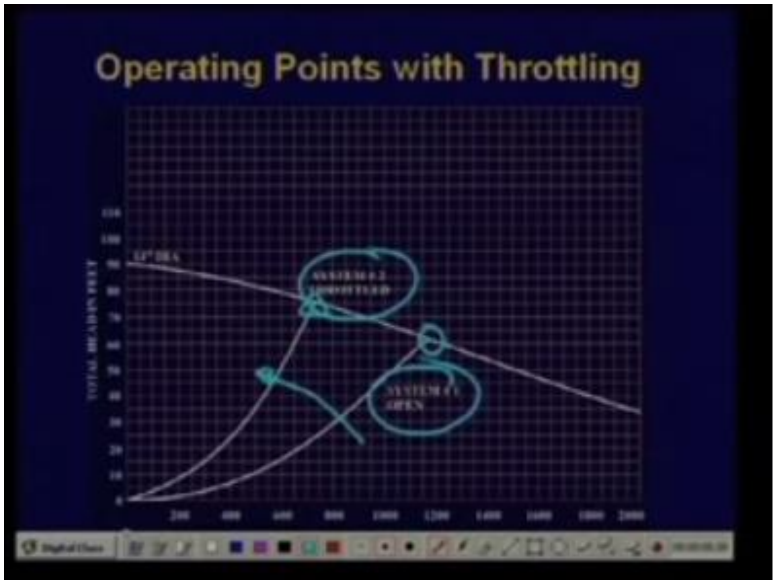
This is going to be tricky now oops I can do this yeah so yep so again you have this pressure and this side you have flow and this side you have you know various rpm you see that so you have this constant horsepower lines and the various speeds also so you see that there are this constant these lines are these various speed lines and these dotted lines as before are the these dotted lines are the constant power lines so it is like the old curve itself okay.

(Refer Slide Time: 22:36)



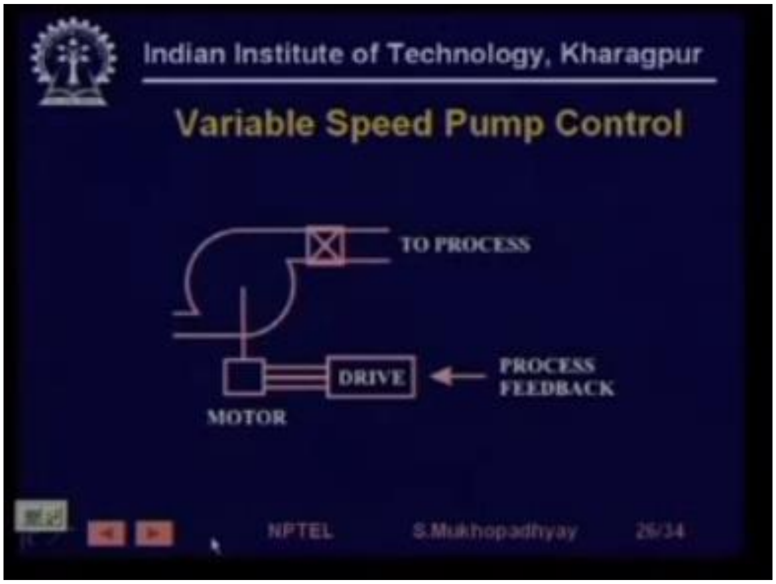
So again in this case previous in the case of fans you put dampers in the case of pumps you put valves right flow control valves which we have already seen in our earlier lesson so that kind of when you close the valve is generally called throttling right so this shows.

(Refer Slide Time: 22:58)



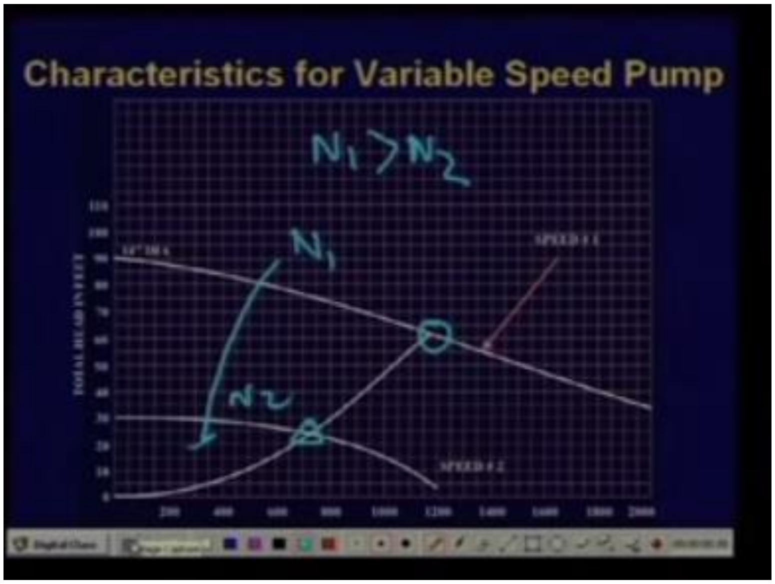
How the operating point shifts if you have one system which is open one system which is open another system which is throttled so again you see that the load curve changes and the operating points will shift from this to this right so the same thing happens here.

(Refer Slide Time: 23:24)



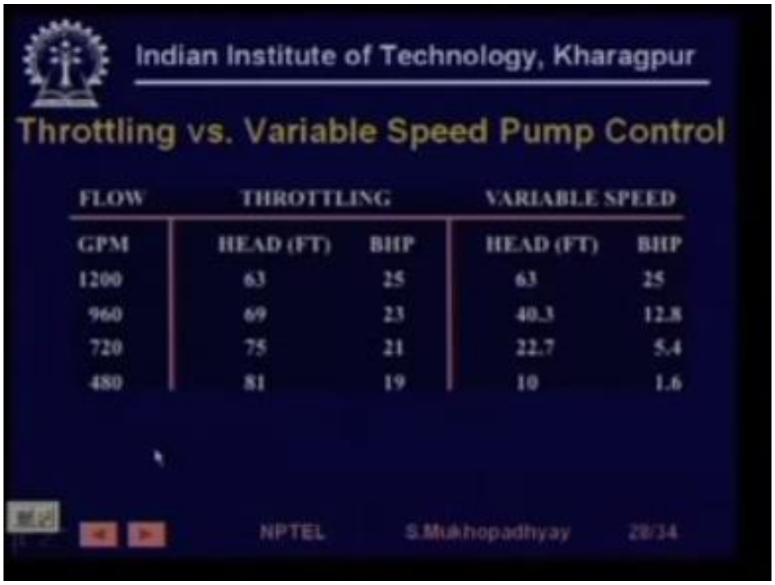
Again for pumps this is a variable speed pump control so you have constant speed drive one way of controlling is either you have a constant speed motor drive and you have a valve or you have a variable speed drive of the pump depending on the feedback depending on the load basically that the drive has to be controlled and some speed references to be given we will see in our future lectures in detail as to how these how the speed of a motor and a pump can be controlled oops.

(Refer Slide Time: 24:02)



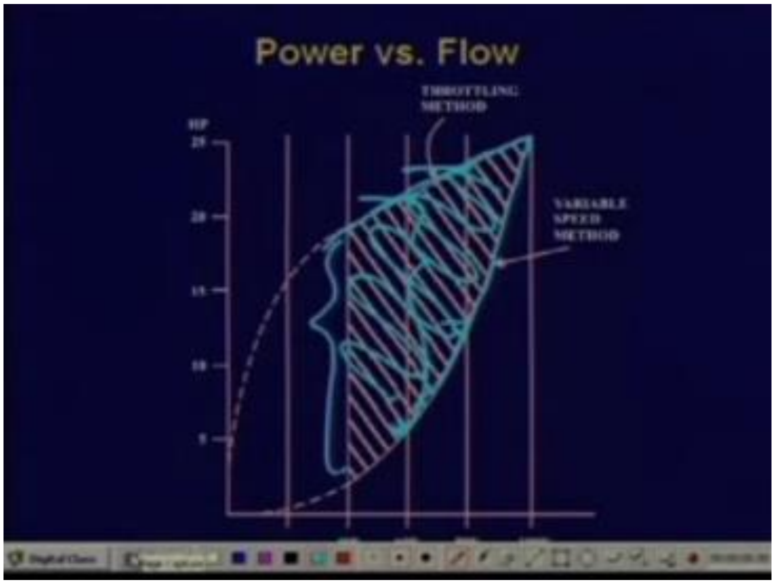
Okay, next now if we control the speed as before the pump characteristic will now come down this is N 1 this is n2 and n 1 is greater than n 2 so the operating points will now shift from this to this okay just like previous case.

(Refer Slide Time: 24:25)



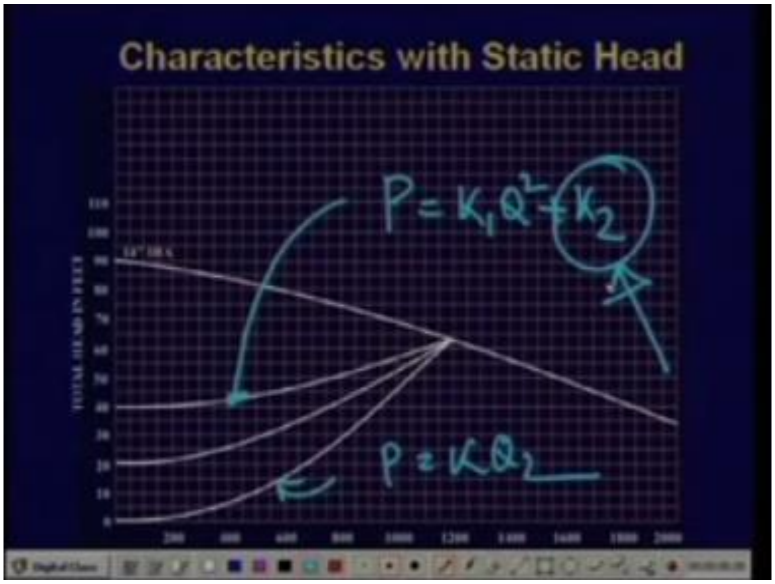
So if you do this do a similar analysis of this pump a similar thing comes out that is see a 1200 the head requirement is and the BHP requirement is 25, 25 at 964 throttling it is 23hardly reduced but for variable speed drive it is much more reduced again because of the fan, fan and the pump laws okay so a similar saving will result that is what.

(Refer Slide Time: 25:05)



So we come back so this is just another depiction that if you have a shows that if you had a throttling method then the energy would have fallen along this path if you have variable speed method it will fall along this path so this is the energy saving that you are getting right now rather the seat any load this is the energy saving that you are getting there is a difference between these two which is substantial.

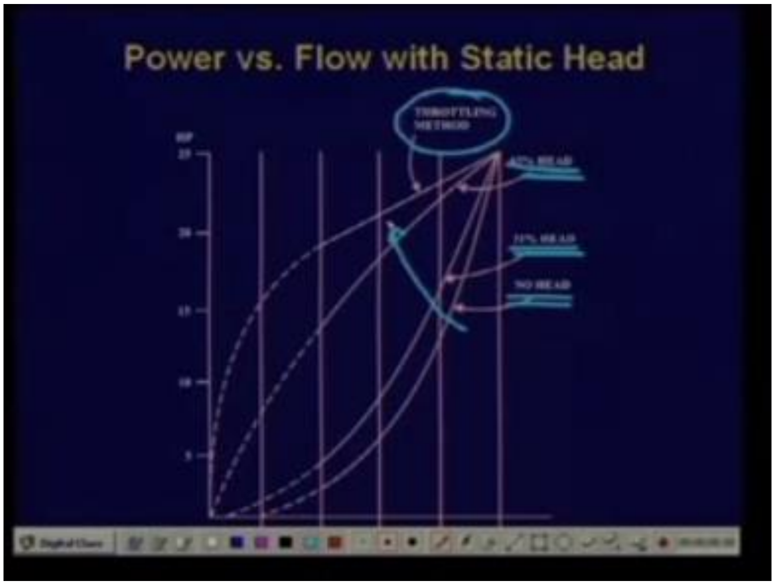
(Refer Slide Time: 25:39)



So only thing is that in the case of the pump there is a there is sometimes pumps operate with a static head so if you have a static head then the load characteristic can be this is one with without static head where p is equal to KQ square type of characteristic but a pump can also operate with the static head where the characteristic is P = k1 Q^2 + k2 so this k2 is the static pressure which is there at the pump Inlet sometimes the pump may be elevated you know so in such a case it has a it has a for example.

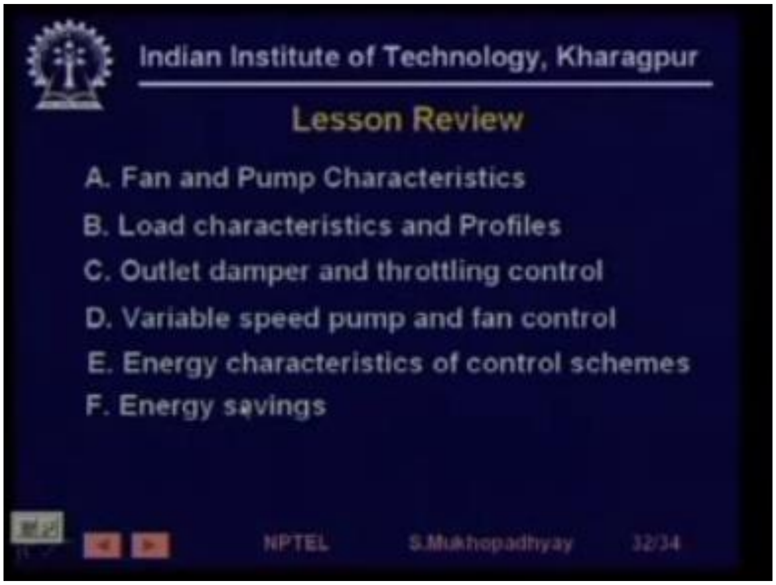
The load the pump may be below and the load may be at a vertical height so even if there is no here is no flow there is a there is always a constant pressure on the pump okay so for driving such loads as we shall see that the energy saving is reduced.

(Refer Slide Time: 26:37)



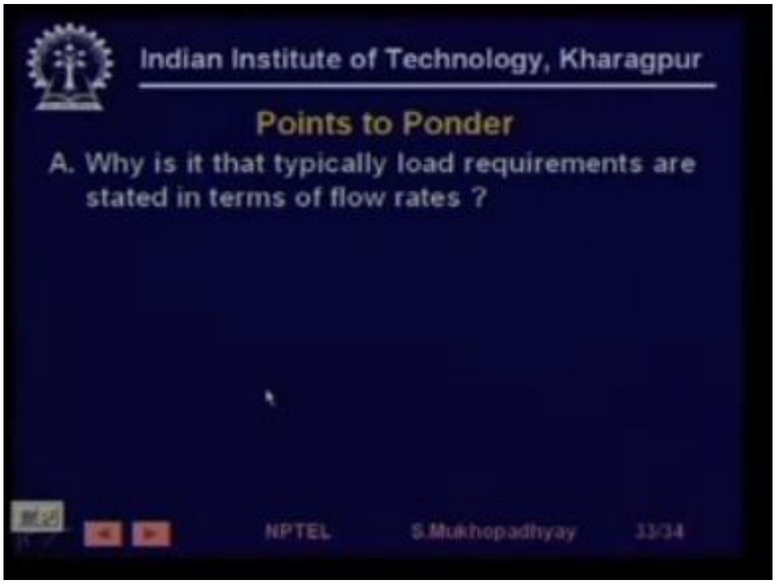
So it turns out that as with static head this is this is this is the throttling method so and this is the variable speed drive method with no head okay this is for thirty one percent head this is sixty-three percent so as the head increases the D the energy saving actually reduces and moves towards the throttling method.

(Refer Slide Time: 27:05)



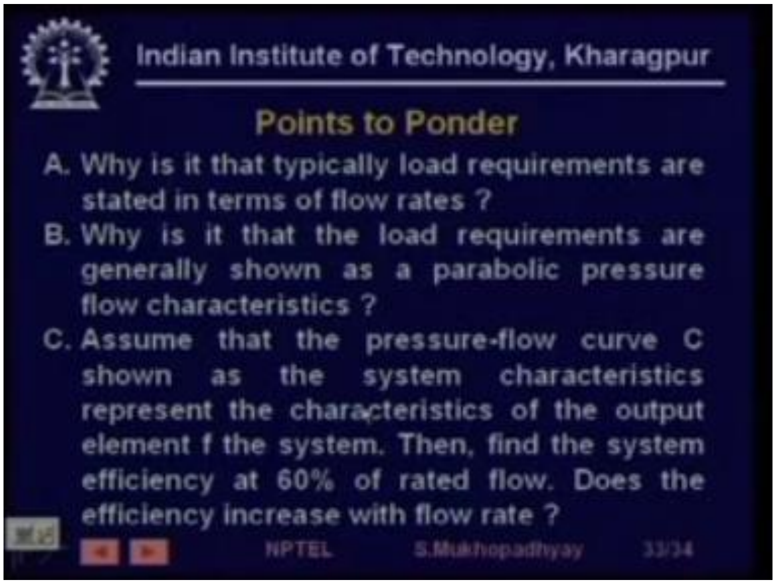
Anyway those are fine points so we have what we have done in this lesson is that we have seen the fanon the pump characteristics we have seen the load characteristics and typical load profiles and we have seen two kinds of control for fans outlet damper and for pumps throttling control and for pumps and fans we have seen the variable speed control and we have seen the energy characteristics of these control schemes and we have even got an idea of the energy savings right.

(Refer Slide Time: 27:43)



So here are a few questions for you why is it that typically load requirements are stated in terms of flow rates why you have to look at the applications.

(Refer Slide Time: 27:48)



And we have discussed this why is it that load requirements are generally shown as parabolic pressure flow characteristics again and third is that from this characteristic it will be interesting if you can if you can find how the efficiency varies does it increase does it decrease as flow is reduced.

(Refer Slide Time: 28:09)

So these are the few questions on which you can ponder and thank you very much.